

A Non-reflecting Branching Filter for Microwaves

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Microwave branching filters are required as integral parts of multi-channel microwave radio relay systems. These filters must have characteristics which are difficult to attain if one attempts to extend familiar lower frequency techniques to the microwave region. A novel network configuration, through which currently anticipated requirements can be met without excessive difficulty, is described in this paper.

In this configuration individual constant resistance channel dropping units are formed of appropriate assemblies of two hybrid circuits, two band reflection filters and two quarter wavelengths of line. An assembly of N channel dropping units in cascade then forms an N channel constant resistance branching network.

The mechanical and electrical characteristics of a practical five channel branching filter of this type are described. As a result of experience with this prototype filter it can be stated with some safety that these requirements can be fulfilled with a network of this type. Experimentally observed impedance, insertion loss and phase characteristics were fully satisfactory. In addition the circuit appears to be flexible enough both electrically and mechanically to fulfill the various types of systems needs which may be encountered at branch points or when channels must be added or interchanged.

INTRODUCTION

PRESENT plans for point-to-point communication by means of microwave radio relay systems call for the operation of several radio channels between each pair of repeaters. A proposed frequency plan for the 4000 mc common carrier band (3700 to 4200 mc) specifies channels 20 mc wide spaced 40 mc center to center. A possible arrangement for a five-channel radio repeater station is illustrated in Fig. 1. This arrangement is calculated to utilize the available frequency space in an efficient and technically sound manner.

If this channel disposition is to be achieved without a costly increase in the number of antennas and the size of the supporting towers, radio frequency branching networks must be provided which connect the individual transmitting or receiving circuits at each repeater point to a common antenna (Fig. 1). If this connection is to be made without excessive loss of power these branching devices must have adequate adjacent channel rejection, low ohmic loss, and good impedance match in the channel bands. An excellent impedance match is especially desirable if circuit disturbances resulting from echoes in the long waveguide lines which lead from the filter assemblies to the antennas are to be minimized (Fig. 1).

Since the type of microwave radio repeater now planned¹ obtains most of its gain at intermediate frequencies, the IF amplifiers will reject all spurious

¹ See H. T. Friis, "Microwave Repeater Research", to appear in the April 1948 issue of *B. S. T. J.*

signals entering the receiver except those in the vicinity of the receiver image bands. Because of this, suppression requirements on the branching filters, except possibly in the vicinity of receiver image bands, are not severe.

Problems connected with the design of suitable microwave branching filters naturally differ considerably from previous filter problems. The discrimination and band utilization requirements are readily met, but the

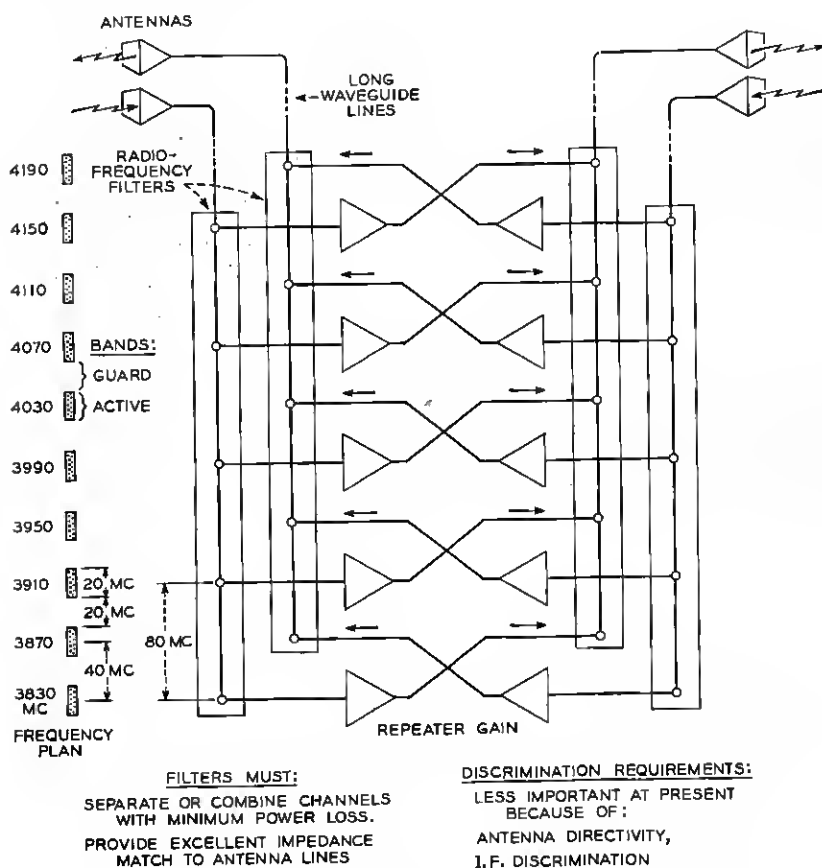


Fig. 1—Possible five-channel radio repeater station schematic diagram.

impedance control required is not easy to obtain by familiar filter techniques. Not more than about 5% variation in impedance or about 0.5 db standing wave ratio in the channels could be tolerated. At lower frequencies channel passing networks which can be connected in series or parallel to form a channel branching filter can be designed on the basis of lumped circuit theory and built of coils, condensers and resistances, but in the microwave region

simple parallel or series connections and simple lumped circuit elements do not exist. Although in the interests of flexibility it would be desirable to add or substitute individual channels without affecting other channels in a branching filter, the convenient possibility of doing so at a high impedance level on vacuum tube grids is not yet available in the microwave region.

A satisfactory two-channel waveguide branching filter has been constructed following partially 'classical' methods. This filter, designed for the New York-Boston experimental radio relay system, is composed of two channel-passing cavity filters each connected to a common input line through one arm of an E plane Y junction, the waveguide analogue of a series connection (Fig. 2). This solution, although relatively simple where only two channels are required, becomes quite complex when more than two are involved, since in every channel the sum of the interactions of all the inactive filters on

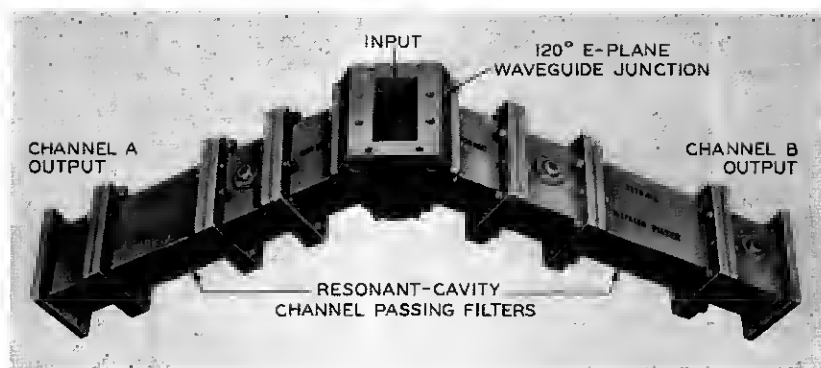


Fig. 2—Branching filter for New York-Boston experimental radio relay system.

transmission through the active filter must be zero. It is evidently not easy to satisfy this condition, particularly since in doing so one must take accurate account of the change with frequency of the effective phase shift of all waveguide connecting lines. And even if such a solution were found it would be valid for only one set of channels, so that the problem must be solved all over again for every change in channel arrangement.

As a result of these difficulties and after a few attempts to overcome them, it became apparent that a more flexible method of microwave filter construction should be found. Constant resistance filters, which provide discrimination by absorbing or diverting the unwanted incident waves rather than by reflecting them, can be useful in any frequency range. In the microwave region, where the shortest connecting pipe may be many wavelengths long, constant resistance devices are particularly helpful. Accordingly a constant resistance channel-dropping network was devised which

could extract one channel from the line, while permitting others to pass through it without disturbance. Several of these networks were then placed in cascade to make up the required filter.

THE HYBRID CHANNEL-DROPPING UNIT

After several possibilities were considered the constant resistance channel-dropping circuit illustrated schematically in Fig. 3 was selected.² This circuit is made up of two hybrid junctions, two identical channel reflection filters tuned to the dropped channel, and two quarter wavelength sections of line.

In order to understand the operation of this circuit, the properties of a hybrid circuit, Fig. 4(a), must first be understood. This circuit, which has

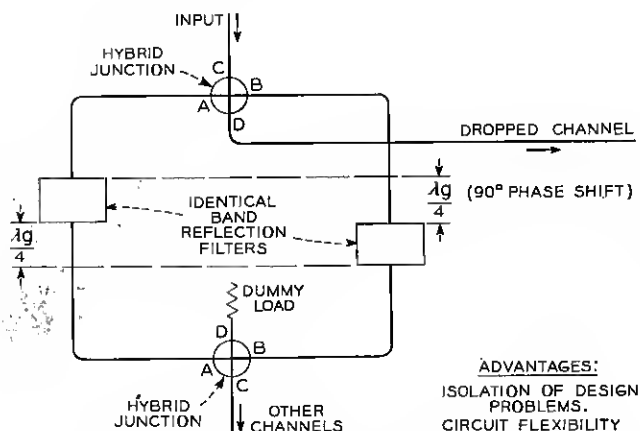


Fig. 3—Possible constant impedance channel dropping filter.

been embodied at voice frequencies as the hybrid coil and at microwaves as the hybrid junction (E-H plane T junction)³ can be represented schematically as in Fig. 4(b). Let us connect four transmission lines, A, B, C, D, each terminated in its characteristic impedance to the four pairs of terminals of the hybrid circuit. Then if each of these lines is matched to the pair of terminals to which it is connected, the following characteristics will result. Power in transmission line C flowing towards the junction will divide equally into lines A and B, flow away from the junction and be absorbed in loads A and B. None of this power will appear in line D or be reflected back into

² Lumped element networks with properties similar to those of this circuit have been devised by Vos and Laurent, U. S. Patent 1,920,041, and Bohis, U. S. Patent 2,044,047. A. G. Fox of these laboratories has independently devised similar microwave circuits.

³ W. A. Tyrrell, Hybrid Circuits for Microwaves, Proc. I. R. E., Vol. 35, pp. 1294-1306, November 1947.

line C. Similarly, power in line D flowing towards the junction, will appear equally in A and B but not in C or back in D. If these characteristics hold, then by the principle of reciprocity similar characteristics must hold for lines A and B. If proper planes of reference are chosen this behavior can be described in a slightly different, but equivalent, manner. If waves in both A and B flow towards the junction the vector sum of the voltages of these times a constant (0.707) appears in C and the vector difference times the same constant appears in D, but nothing is reflected back into A or B. An equivalent statement can be made if the waves start in C and D.

With the properties of the hybrid in mind, and if it is assumed that the hybrids, the identical reflection filters and the quarter wave lines are perfect and free of ohmic loss, the operation of the circuit of Fig. 3 is easy to understand, and is as follows: A wave entering from arm C of the input hybrid is divided equally into the two arms A and B. None of the power in this wave

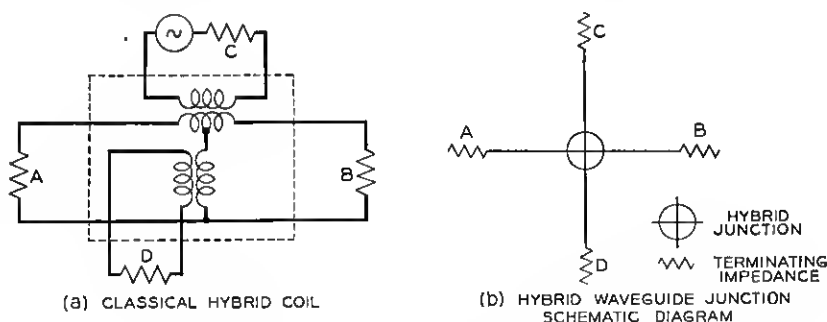


Fig. 4—*a.* Classical hybrid coil.
b. Hybrid junction schematic diagram.

is reflected back into the arm C or appears initially in arm D. The two equal components of the wave now travel along the lines which are connected to the arms A and B of the input hybrid. If the frequency lies outside the band of the reflection filters the waves travel through these filters and appear in phase in the arms A and B of the output hybrid. The vector sum of these two waves appears in the arm C of the output hybrid and has an amplitude equal to that of the original input wave. Consequently all energy in the input line incident on this network, except that lying in the band of the reflection filters, will pass through it to the output line.

If now the frequency of the input wave lies within the band of the reflection filters, the two equal components of the wave traveling away from the input hybrid will be reflected at the filters and will travel back towards the input hybrid. One of these components must, however, travel twice through an extra quarter wavelength of line, and will therefore be reversed in phase; with

respect to the other component when it reappears at the input hybrid. The two components will consequently combine in the fourth or difference arm of the input hybrid to form a wave equal to the original input wave.

The circuit of Fig. 3 is only one of a general class of hybrid filter circuits. From one viewpoint these circuits resemble spectroscopes, and, from another, ordinary lumped circuits. We could, for example, replace the band reflection circuits of Fig. 3 with any two identical four-terminal networks. This circuit would still retain its constant resistance character. One of its branches would contain all energy reflected by the four terminal networks; the other would contain all energy passed by them.

In particular if the two identical filters are of the channel passing type; input waves within this channel will be transmitted by both filters and will combine at the output hybrid and appear in arm C. All of the other channels will be reflected by the filters and thus will appear in arm D of the input hybrid, provided that the assumed 90° phase shift holds over a band which includes all of the channels.

The particular configuration of Fig. 3 was chosen to minimize the effect of practical limitations. The dropped channel width (20 mc) is only a small fraction of its midband frequency (about 4000 mc). Consequently when band reflection filters are used in Fig. 3, the change with frequency of the nominally quarter wave sections of guide does not seriously affect the performance of the filter and the impedance match of arm D of the hybrids needs to be good only in the vicinity of the dropped channel.

The circuit shown in Fig. 3 is a constant resistance network which drops the channel corresponding to the reflection filter. Several in sequence as indicated in Fig. 5 constitute a constant resistance channel branching filter. In the sections to follow we will give an account of the physical configuration and electrical performance of a branching network designed according to this pattern to meet the radio frequency requirements of a typical practical radio relay system containing five 20 mc radio frequency channels, spaced 80 mc center to center.

THE WAVEGUIDE HYBRID

In choosing a hybrid configuration which could be successfully used in the network of Fig. 5, both electrical and mechanical requirements were considered. Since frequency f_n passes through $2n-1$ hybrids it is evident that if acceptable overall performance is to be obtained, the balance and impedance characteristics of each hybrid must be excellent. A broad-band balance can be obtained with relative ease by attaching the 'driven' arms (A and B on Fig. 5) symmetrically. Fortunately the strict impedance requirement applies to only one of the two 'driving' arms (C and D), the other being required to transmit only a single channel.

Because of the reentrant nature of the circuit of Fig. 5 it is evidently desirable, if not essential, to employ a hybrid with a convenient mechanical layout. If, for example, a familiar E-H plane junction type of hybrid were used in combination with waveguide filters built in a straight piece of waveguide, twenty-four E or H plane right angle waveguide bends would be required in the construction of each six-channel branching network. To avoid this extra complication and expense a hybrid configuration with 'driven' output arms parallel to the well matched 'driving' input arm was sought.

The hybrid configuration settled upon was the one shown in Fig. 6. Here the electrical and geometrical requirements discussed above are met simultaneously by connecting the driving arm C to the symmetrically located driven arms A and B through a smoothly tapered E plane Y junction. The taper is approximately one half wavelength long in the center of the 3700-4200

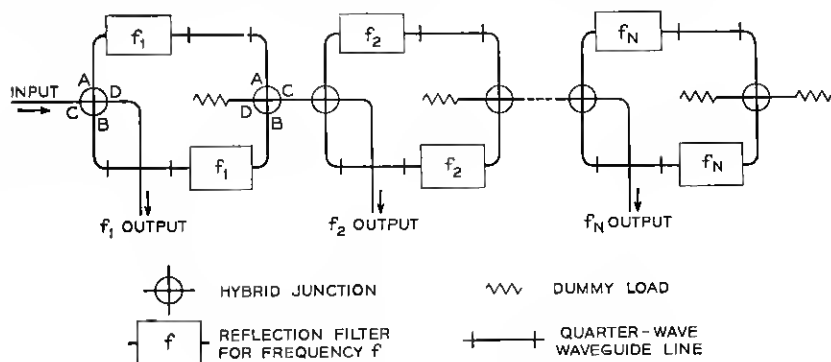


Fig. 5—N Channel branching filter.

mc band. The driving arm D is connected to arms A and B through a coaxial line. This line is coupled to waveguide D by means of a conventional probe. The center conductor traverses the Y junction space in such a way that it is normal to the electric vectors of guides A, B, and C, and is effectively coupled to A and B but not to C by means of a probe P fastened through it normally (Fig. 6).

THE BAND REFLECTION FILTERS

The ideal reflection filter for the circuit of Figs. 3 and 5 would reflect perfectly within a certain band and pass perfectly outside of this band. However, the ratio of bandwidth to band spacing in a given branching filter (20 mc to 80 mc) is such that a sufficiently good approximation to this ideal can be obtained in theory if each reflection filter employs only three resonances, Fig. 7(a). These could be effectively series resonant circuits placed at quarter

wave intervals along the guide, properly distributed in impedance level and all tuned close to the center frequency of the channel to be extracted, Fig 7(b). The practical question was to find how to obtain these resonances in an easily constructed and adequately adjustable form.

Early experiments indicated that a probe inserted in the broad side of the guide far enough so that its end formed an appreciable capacitance with the opposite side could be made to resonate in a series resonant fashion. Impedance levels available through this means of coupling were, however, far lower than required. Accordingly an alternate method in which the probe is

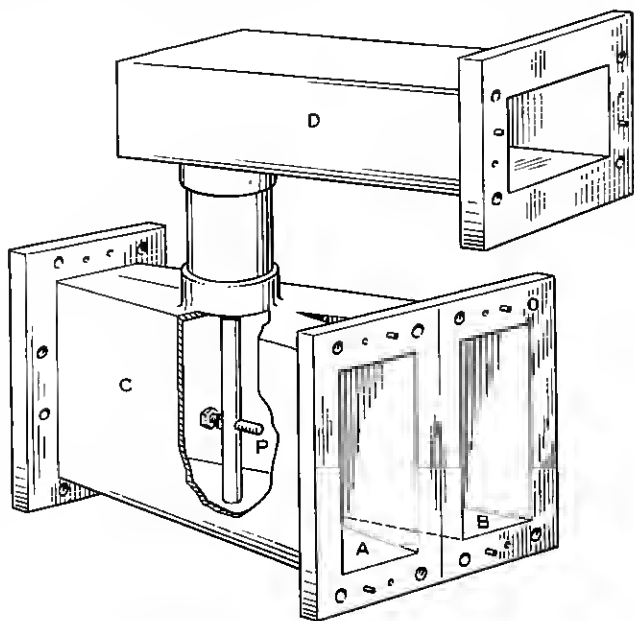


Fig. 6—Hybrid junction.

inserted in the narrow side of the guide was selected (Fig. 8). The probe is made long enough to approach the opposite narrow wall of the guide and is tipped by a capacitive disk. The capacity of the disk and consequently the resonant frequency of the circuit is adjusted by means of a screw in the wall just opposite the disk. Since this rod is inserted perpendicular to the narrow guide wall it is normally uncoupled to the principal mode in the guide. An adjustable coupling is achieved by inserting a screw in the broad side of the guide just above the probe. Insertion of this screw disturbs the symmetry of the field and couples the rod to the guide. Increasing the screw insertion increases the coupling and consequently varies the impedance level of the

equivalent series resonant circuit continuously from infinity down to any value within the range required.

It should be pointed out that impedance and frequency adjustments are not in practice completely independent, but do at least permit the realization of any required value. Furthermore, mutual coupling between the probes interferes with the exact realization of the circuits of Fig. 7. This coupling does not interfere, however, with the realization of satisfactory filter characteristics.

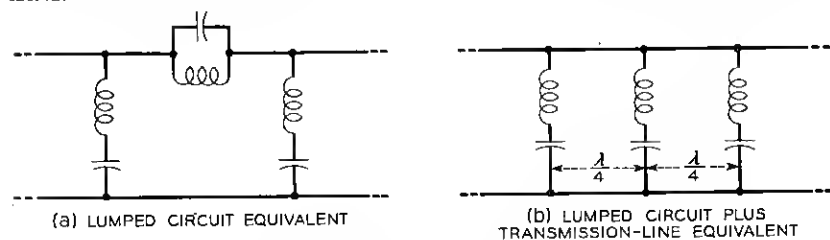


Fig. 7—Band reflection filter.

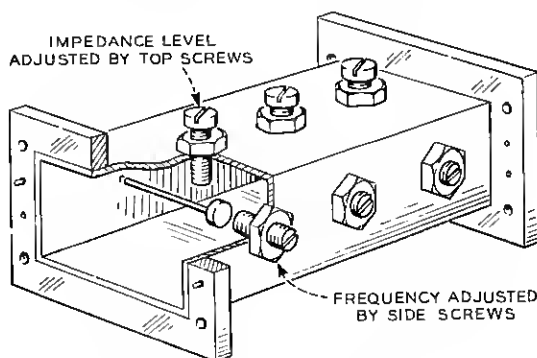


Fig. 8—Waveguide band reflection filter.

When the reflection filter of Fig. 7 was embodied in waveguide form through use of the series resonant circuits just described, the configuration illustrated in Fig. 8 resulted. It was found that, with the exception of a slight change in disk to guide wall spacing, a single configuration could be tuned to any of the desired channels.

ELECTRICAL PERFORMANCE

Individual components as described above were constructed, adjusted and assembled to form a five-channel branching network (Fig. 9). The electrical performance of this network was trimmed systematically, then was measured

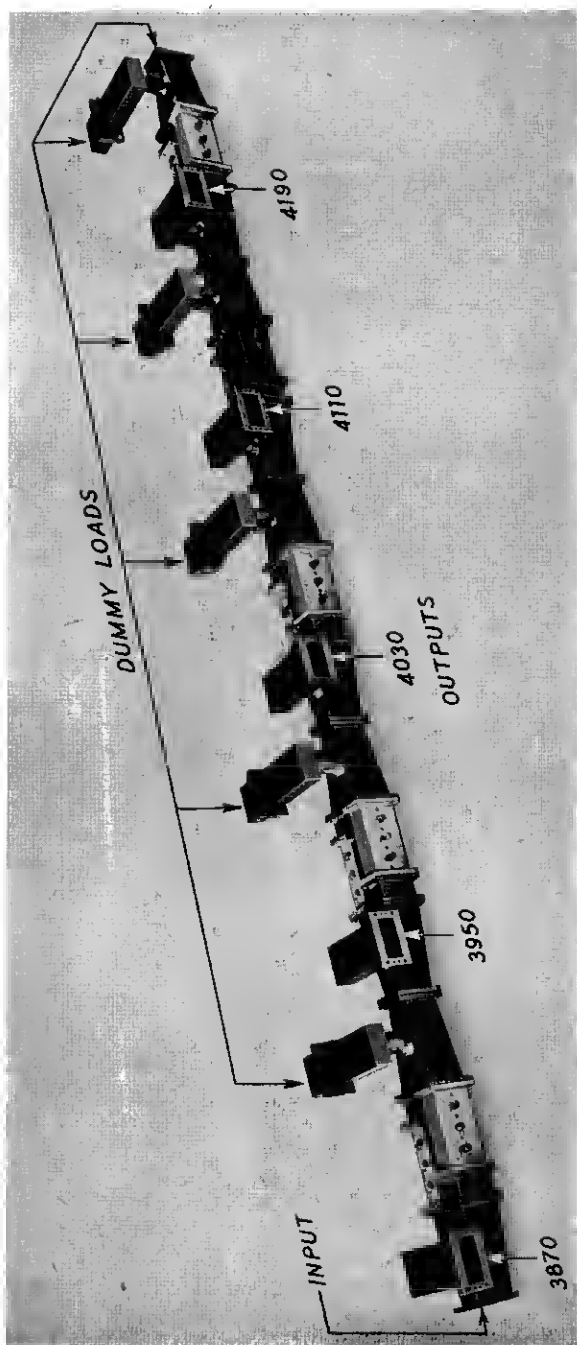


Fig. 9—Five-channel branching filter.

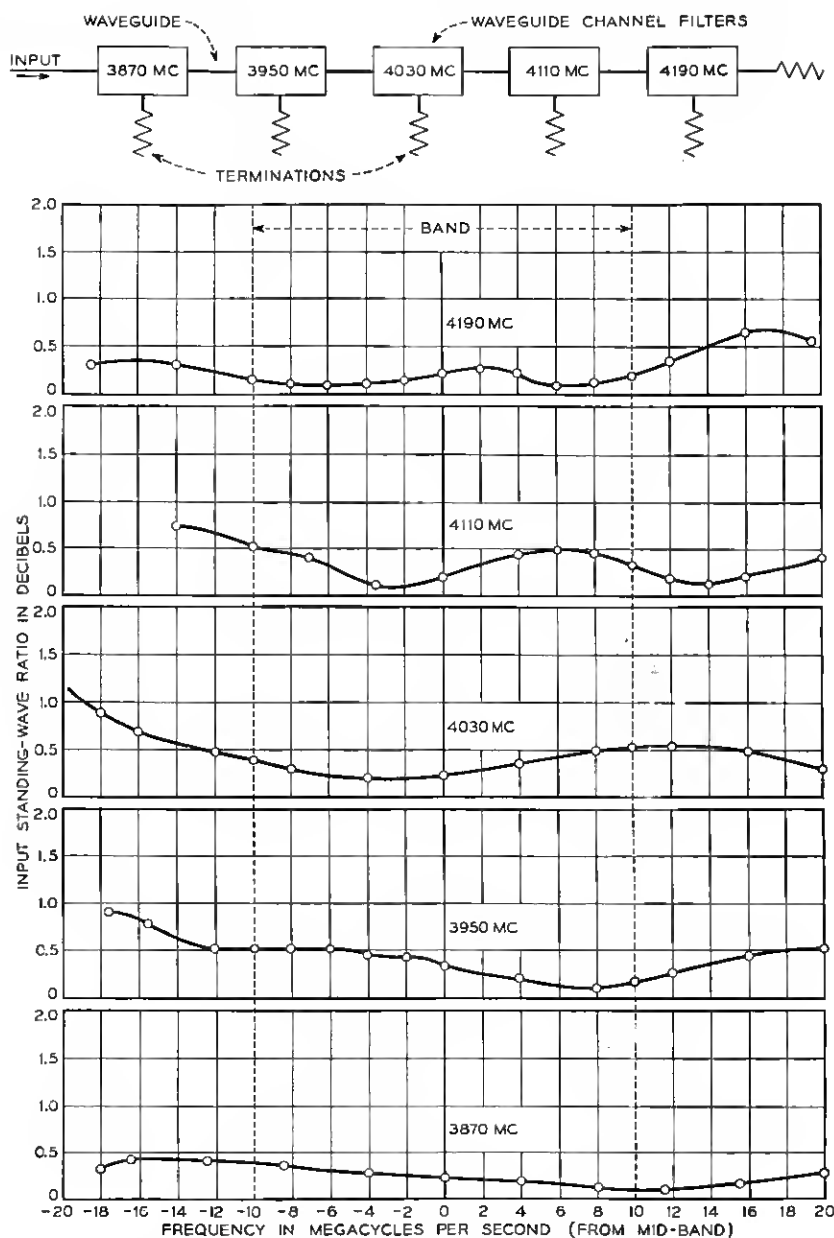


Fig. 10—Input standing wave ratio of hybrid branching filter.

point by point with a double detection measuring set. With all outputs terminated the standing wave ratio observed at the input line was under 0.6 db in

all channels. This quantity is plotted in Fig. 10. The insertion loss measured between the input line and the various output lines varied from about 0.5 db in the lowest frequency channel closest to the input to about 1.0 db in the highest frequency channel farthest from the input. This loss is plotted in Fig. 11. Since 0.5 db was approximately the loss observed in each individual

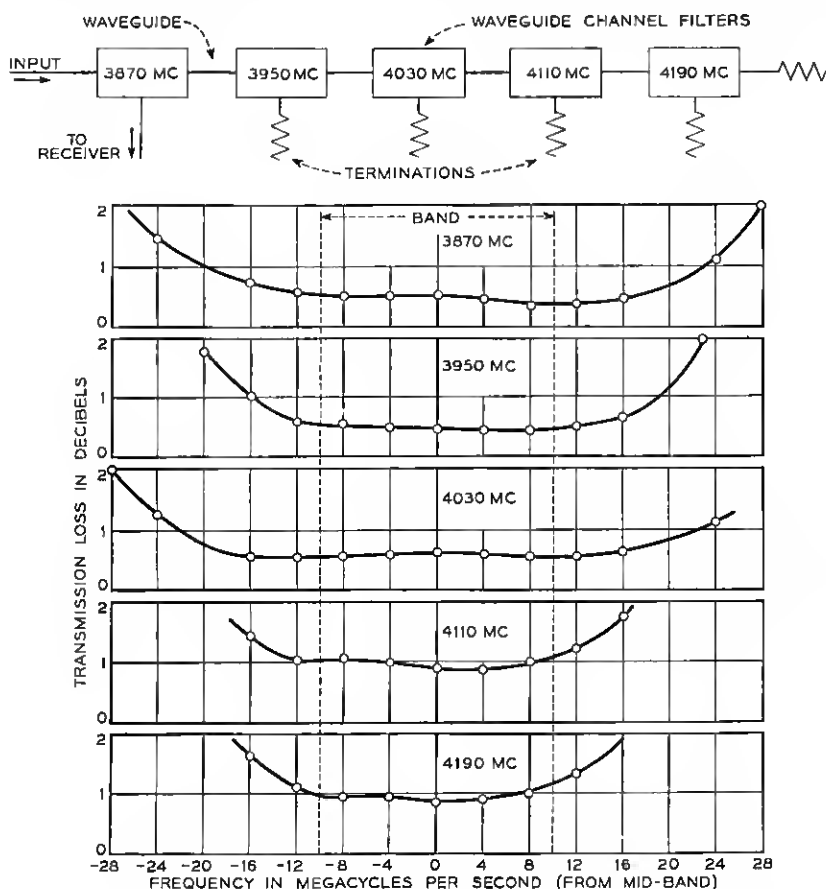


Fig. 11—Transmission loss of hybrid branching filter.

channel dropping unit, it appears logical to assume that the progressive increase in loss is due to passage of the higher frequencies through the lower frequency circuit components.

The measured discrimination against other channels and image responses was 20 db or more. This modest amount of selectivity is sufficient since the primary function of the present filter is branching, and hence the amount of

discrimination needed is only that required to prevent a significant energy loss in the channel bands. If crosstalk considerations indicate that more r-f discrimination is required, this can be obtained by placing auxiliary filters in the branch arms. This can be done without complication since the branching filter is a constant resistance device.

The delay distortion was examined but was found to be less than the errors of measurement, i.e. 2 millimicroseconds.

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